NAVAL RESEARCH

REVIEWS

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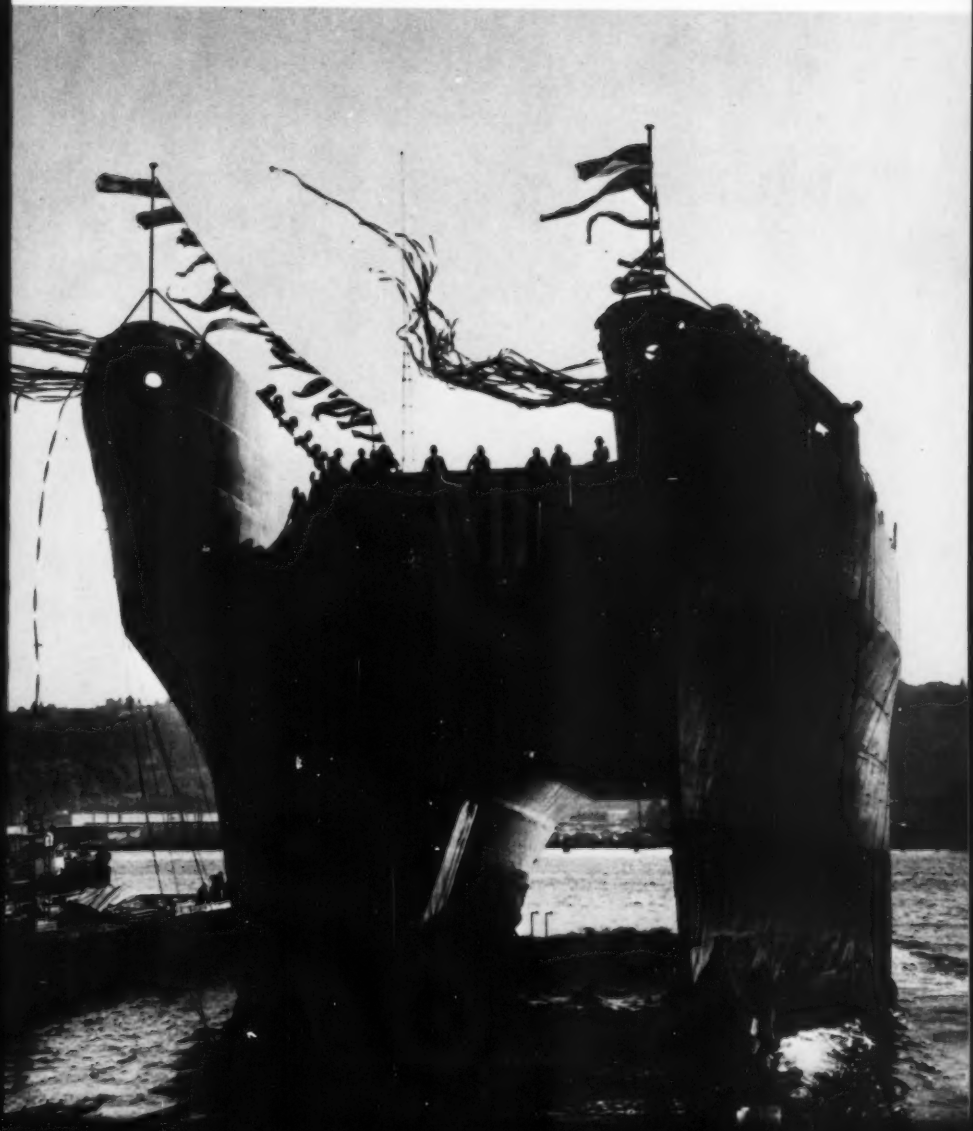

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Portraits in Science

Dr. William M. Fairbank

Dr. William M. Fairbank's most important scientific achievements have been in the field of cryogenics, where he has emphasized research on the properties of matter near the absolute zero of temperature. He has made major contributions to research in the fields of superconductivity, liquid helium-4 and liquid helium-3. For his outstanding work in physics, Professor Fairbank was named California Scientist of the Year in 1961. He is a Fellow of the American Physical Society and a member of the National Academy of Sciences and the American Academy of Arts and Sciences. Dr. Fairbank received his PhD from Yale in 1948 and then taught at Amherst College and Duke University. Since 1959 he has been a Professor of Physics at Stanford University. Over the years Dr. Fairbank has directed many ONR research projects.

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Superconducting Technology

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Introduction

Ever since the discovery of superconductivity in 1911 and discovery of the superfluid properties of liquid helium in 1937, it has been recognized that low temperatures provide electrical and thermal properties unique in nature and which could be of great technological importance. Yet as late as 1952, at a Low Temperature Conference at General Electric, the principal speaker stated that low-temperature physics represented an ivory tower of field of research, a field which would never become commercially practical. To that speaker it was inconceivable that anyone might cool a large-scale commercial system to liquid helium temperatures in competition with a room temperature system.

Since the development of the cryotron in 1956 by Dudley Buck and the development of high-field superconducting magnets by Kunzler in 1959, considerable effort and discussion has been directed toward the possibility that here at last were large-scale practical applications of superconductivity. Still, as of today, superconducting computer elements have yet to be produced commercially and superconducting magnets are mainly designed for modest, basic research programs, although this latter field is growing steadily and several large scale magnets have been built for high energy physics. One of the reasons that more use has not been made up till now of low temperature devices in practical applications is the difficulty of providing the necessary refrigeration. Usually a single device is cooled in a dewar to liquid helium temperatures and one has both the problem of providing this specialized refrigeration and the interface problem between this particular device and the rest of the apparatus which is usually at room temperature.

The superconducting accelerator and large scale cryogenic system are two major low temperature programs, which could have important application to the Navy.

The primary objective for the Office of Naval Research is to investigate low temperature phenomena and exploit the associated technology in conjunction with the design, development, construction, refrigeration, and test of superconducting high power microwave accelerator cavities. This includes large-scale cryogenic experiments on the transport and

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refrigeration properties of superfluid helium over distances of several hundred feet. This work is significant in demonstrating the potential of large-scale cryogenic technology for application to electronic systems such as aboard ship at helium temperatures. The equipment would be compact, highly reliable, and efficient and would require less power.

This work also concerns the development of a large-scale cryogenic technology in conjunction with the development of nuclear techniques and associated high-power electronics for application to electronic systems such as aboard ship.

Superconducting Accelerator

The present superconducting accelerator (SCA) program at Stanford is the outgrowth of a major effort which began in 1961. It was clear from the outset that a practical SCA represented a technological development of significant proportions and that this development would come to fruition only through a long-range research program and through continued financial support. The SCA program required development of a new superconducting technology to produce high power superconducting microwave cavities with Q's (quality factor) exceeding 10^{10} (a million times higher than room temperature copper cavities), and the development of a new super-fluid helium technology to handle the large power dissipation at low temperature while maintaining near-isothermal conditions over distances of hundreds of feet. In addition, the SCA program required a major engineering effort in integrated large-scale cryogenic systems to satisfy new and exacting standards for reliability and convenience of operation. Although in 1961 three independent groups (at the Rutherford Laboratory in England, at CERN in Switzerland and at Stanford in the USA) initiated studies related to the feasibility of the SCA, of these only the program at Stanford has survived the technological obstacles.

What is a linear accelerator and why do low temperatures offer such a tremendous possibility for improvement?

As illustrated in Figure 1, the linear accelerator is a linear chain of microwave cavities. The individual cavities are coupled to their neighbors through a hole on the accelerator axis so that the entire assembly resonates as a single microwave structure. For the $\pi/2$-mode shown in the figure, the electronic field E in one-half of the cavities is zero while the electric field in the remaining cavities lies along the accelerator axis and alternates in direction (*i.e.*, alternates in phase) from one excited cavity to the next. The time variation (frequency) of the accelerating fields and the length of the individual cavities are adjusted such that the electrons, which are traveling at the speed of light through the

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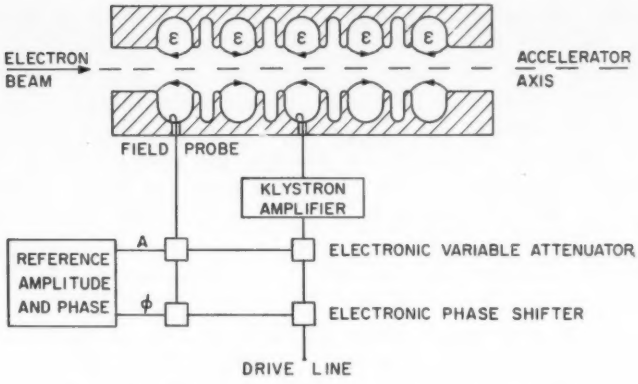

Figure 1 — Bi-periodic π/2-mode accelerator structure with electronic feedback stabilization

accelerator, stay in phase with the accelerating fields and absorb energy from each of the excited cavities.

Associated with the intense electric fields along the accelerator axis, large high-frequency currents flow in the walls of the individual cavities. In a conventional accelerator operating at room temperature, these currents result in power dissipation on the order of 10^6 watts per foot if an energy gain of a few MeV per foot is desired. At this enormous power level the linear accelerator can only be pulsed on for a very brief time interval, typically a few microseconds. Thus for a repetition rate of a few hundred pulses per second, the duty cycle, or the fraction of the total time that a beam is accelerated, is only 10^{-3} and represents a serious limitation of the conventional accelerator, especially for coincidence experiments. Furthermore, during a beam pulse that is only a few microseconds in duration, transients are important and limit the energy resolution that can be achieved to the order of one percent. Since the power dissipation per foot increases as the square of the energy gain per foot, the enormous power levels required also limit the energy gain that can be attained in a conventional linear accelerator.

Low temperature techniques are particularly important in the linear accelerator, first because they open the possibility of continuous operation of the accelerator at very high energy gain per unit length, and second because they open the possibility of exceptional stability and resolution. Continuous operation of a linear accelerator at high energy gain can only be achieved if the accelerator cavities are fabricated from an appropriate superconducting material and operated at liquid helium temperatures. The high frequency surface resistance of a superconductor vanishes exponentially with decreasing temperature and for pure niobium at

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$\simeq$ 1 GHZ and temperatures just below 2°K it is a factor of 10^6 to 10^7 smaller than the high frequency resistance of pure copper at room temperature. Thus the power per lineal foot that is dissipated in the cavity walls in continuous operation of a superconducting linear accelerator is on the order of 1.0 watt per foot which is entirely manageable, even at these low temperatures. Further, the power level no longer represents a practical limit on the energy gain; and thus it is possible to increase the accelerating field until one is limited by the critical magnetic field of the superconductor or until one is limited by pre-breakdown field emission currents. For superconducting niobium at temperatures just below 2°K, the critical magnetic field defines a limit to the energy gain that is about 12 MeV per foot. If the accelerator were constructed as a traveling wave resonant ring instead of a standing wave resonant cavity as assumed above, an energy gain of 20 MeV per foot could in principle be attained. Coincidently, the limit to the energy gain that is defined by the critical magnetic field seems to be very near the pre-breakdown field emission limit that is observed in the best copper cavities at room temperature.

The new low temperature techniques also permit a dramatic improvement in the stability and resolution of a linear accelerator. As already mentioned, in a conventional linear accelerator the transients which occur during the beam pulse limit the energy resolution to about one percent. For a superconducting accelerator, which operates continuously, transients are no longer as important; and one has at the same time an excellent opportunity to use feedback control to achieve maximum stability. Although the power dissipation in the individual cavity walls is important from the cryogenic viewpoint, it is otherwise negligible. Thus we can look at the superconducting cavities which comprise the linear accelerator as an energy storage system or "flywheel," in this case for high frequency electromagnetic energy. As illustrated in Figure 1, the electron beam extracts power from this "flywheel;" but the amount of energy stored is so large compared to the rate it is extracted, that the accelerating fields in the cavity can not change significantly in a time scale less than one millisecond. This is an ideal situation for the use of electronic feedback, as indicated in Figure 1, and thus stabilization of the accelerating fields to one part in 10^4 can be readily achieved. For a linear accelerator special care must be taken to see that every electron is very nearly in phase with the accelerating fields, for otherwise, despite the excellent stability in time, there will be an inherent spread in the electron energies. The energy gained by an electron will vary as the cosine of its phase relative to the accelerating field, so if all electrons are to gain the same energy to within one part in 10^4, they must be confined to a bunch that is $\pm$ 1° in width.

In order to achieve the extremely small power dissipation noted earlier, it is necessary to operate a superconducting linear accelerator

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at temperatures below 2°K. This is a very great advantage, since below 2.18°K liquid helium becomes a superfluid and exhibits nearly perfect heat transport properties. The extraordinary heat transport properties of superfluid helium coupled with its large heat capacity (near 2°K the heat capacity of liquid helium is comparable to that of water at room temperature) make it an ideal thermal reservoir in which the superconducting accelerator can be immersed. With superfluid helium the entire accelerator can be maintained at constant temperature within 10 millidegrees Kelvin which contributes greatly to the stability of operation. This, to our knowledge, is the first practical large-scale application of superfluid helium.

At Stanford the immediate objective of the SCA program is the construction of a superconducting electron linac that can provide an intense electron beam of the highest quality. Facilities for this unique accelerator include a linac tunnel 600 feet in length, a central refrigeration plant capable of removing 300 watts at 1.85°K, and 200 kilowatts of rf (radio frequency) power available for the beam. In 1967, based on a generous extrapolation of our early experiments, we expressed confidence that a superconducting electron linac could be constructed in our laboratory which ultimately might yield the operating characteristics indicated in Table I. Steady progress in the development of the SCA has convinced us that our original projections, as outlined above, can be achieved and in some cases might even be improved upon.

TABLE I

Energy	2 GeV	1 GeV	200 MeV
Duty Cycle	100%*	100%	100%
Average Current	100 μa	200 μa	1 ma
Energy Resolution	10^{-4}	10^{-4}	3×10^{-4}

*The realization of a 100 percent duty cycle at 2 GeV depends on the actual shunt impedance achieved in the final accelerator. In any case 100 percent duty cycle will be possible with the aid of a second refrigerator.

The increasingly obvious success of the superconducting electron linac program at Stanford has encouraged others to explore the possible applications of these novel low temperature techniques to their own research interests. Among nuclear physics groups in this country, for instance, the California Institute of Technology has initiated a program to study the possibility of constructing a superconducting linac for protons and light ions in the region of a few hundred MeV; the University

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of Illinois has embarked on a program to construct a superconducting racetrack microtron for electrons in the region of 600 MeV; the Los Alamos Scientific Laboratory is considering the possibility of using a superconducting linac for the acceleration of a beam of π-mesons; and several laboratories that have proposed machines for accelerating heavy ions up to uranium are now considering the possibility that these research objectives could be accomplished best using superconducting techniques. Among particle physics groups, the Brookhaven National Laboratory is investigating the possibility of constructing a superconducting rf separator for use in conjunction with the Alternating Gradient Synchrotron (AGS) and the Stanford Linear Accelerator Center is studying the feasibility of ultimately converting their machine to a 100 GeV superconducting electron linac. Each of these programs involves a different field of research of considerable scientific importance, and the High Energy Physics Laboratory at Stanford has contributed directly to each of these programs by extended technical discussion and by making available its special facilities.

We have already pointed out the important technical advantages that are inherent in superconducting linacs, namely, the high duty cycle and high energy gradient, and the excellent stability and resolution; but it is also important to emphasize the inherent economic advantage of the superconducting linac. Conventional high duty cycle linacs, whether for protons or electrons, are necessarily designed to operate at very low energy gradients. Although a superconducting linac is unquestionably more expensive per lineal foot than its room temperature counterpart, perhaps by as much as a factor of two, the design gradient can be approximately an order of magnitude higher and thus the cost for a given accelerator is less by approximately a factor of five. This argument, although clearly over-simplified, describes the essential factor determining the comparative economics of room temperature and superconducting linacs. It seems clear that low temperature techniques will have a major impact on the the future development of nuclear physics and particle physics.

Applications of these novel low temperature techniques are not limited to nuclear physics and particle physics. At Stanford we are considering, for instance, the possible use of the very high resolution electron beam that can be achieved in a superconducting electron linac in the construction of an x-ray laser based on stimulated Compton scattering. In addition we are considering the possible use of low temperatures on a large scale in the detection of gravitational radiation, the possible use of high Q superconducting cavities for rf confinement and acceleration of plasmas, the possible use of superconducting linacs as an inexpensive meson factory for the production of negative pi-mesons which could be important in the radiation treatment of cancer, and the possible use of

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high Q superconducting cavities in stable, but tuneable, oscillators, or in clocks.

Cryogenic System

The cryogenic requirements of a superconducting accelerator are substantially different from those of any existing large system cooled by liquid helium. The accelerator system must span a large distance, the temperature that is required is low, below 2°K, and the accelerator structure for its proper operation must be maintained in a very stable mechanical and thermal environment. In addition, the device is fundamentally dissipative so that large heat loads must be provided for.

Therefore in planning a system for the most economical construction and operation, a balance must be struck between the loss of efficiency in carrying the refrigeration several hundred feet with little allowed pressure drop and the gains in efficiency and decreased cost of one large refrigeration plant as against several smaller ones. At this time it is clear that very low-loss insulated pipe lines for liquid helium are economical to build and that not only the superconducting accelerator but any other medium or large low temperature apparatus in the laboratory as well should be refrigerated from a single plant.

A schematic of the cryogenic system under construction for the High Energy Physics Laboratory is shown in Figure 2. This system naturally divides into 3 parts: the refrigeration plant, the accelerator dewar tanks, and the distribution system which connects them. Each of these parts is briefly described below:

(a) Refrigerator: This piece of equipment was designed and built by the C.T.I. subsidiary of A. D. Little, Inc. It is installed in a room

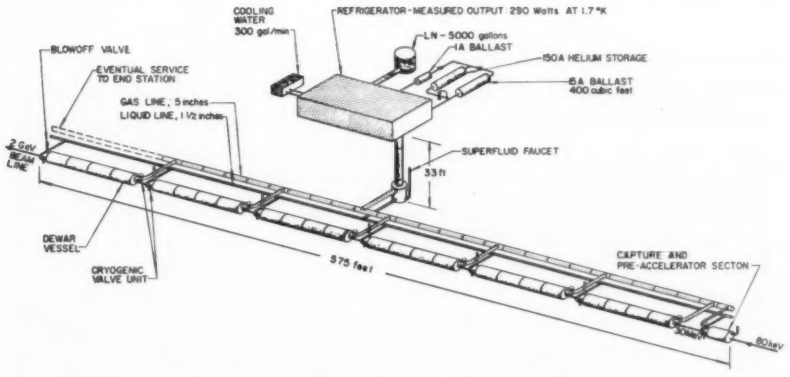

Figure 2 — Block diagram of cryogenic system

about 20 by 40 feet and consists of four Roots-type compressors, two large reciprocating compressors, and a vacuum insulated unit containing heat exchangers and two reciprocating expansion engines. A photograph of the plant is shown in Figure 3.

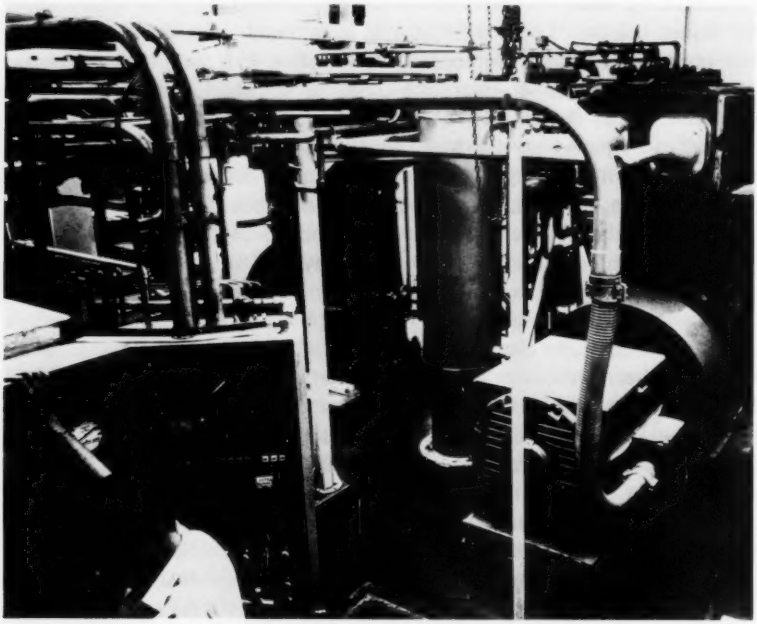

Figure 3 — Refrigeration plant

The specifications for this superfluid helium refrigerator called for 300 watts of cooling at 1.85°K; and in recent tests these requirements have been met and the system has operated for several days at 290 watts at 1.7°K. The machine requires 500 KW of electric power, about 70 liters/hr. of liquid nitrogen and 300 gallons/min. of cooling water for its operation. The efficiency of the refrigerator between 1.7° and 800° is about 2.5 percent of the Carnot value, and taking an equivalent dollar value of electric power for the nitrogen input, the overall efficiency between 1.7 and 300°K is about 6 percent of Carnot. A year's operating expense, not including depreciation or labor costs appears in Table II. These figures include the cost of liquid nitrogen for the shielding in the cryogenic piping and the accelerator dewar system.

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The plant delivers refrigeration isothermally by producing liquid helium at the operating temperature and accepting helium gas also at the operating temperature and saturated vapor pressure which at 1.85°K is 15 torr.

Table II
Yearly Operating Expenses of Cryogenic Systems

500 KW power at $0.012/kwhr	$ 50,000
70 liters/hr. LN_2 at $0.05/liter	30,000
40 liters/hr. LN_2 for shielding	18,000
Loss of He gas	1,000
Service of Water system	1,000
	$100,000

(b) Dewar Vessels: Each of tne twenty-four 20-foot accelerator sections is contained in a 20-foot dewar module which consists of a 2-foot diameter helium vessel, a 3-foot diameter vacuum jacket, and in the annulus between, a nitrogen-cooled shield with multi-layer insulation.

A module can be operated as a single 20-foot dewar by putting cap assemblies on the ends, or it can be coupled directly to another module to form a longer dewar tank. Thus one has considerable flexibility in assembling the accelerator in the most convenient way for operation and servicing. The expected arrangement is the one shown in Figure 2; that is, coupling the 20-foot sections in six groups of four plus a special dewar for the injector sections. This results in a cryogenic system of seven independent units connected to the refrigerator through the manifold piping.

The system will be operated about half full of superfluid helium which is about 30 liters of liquid per foot of accelerator. The remaining volume provides storage space for liquid when one of the dewars is warmed up for repair or for other uses in the laboratory.

One of the two 20-foot prototype units that we have been testing for almost a year is shown in Figure 4 in the process of assembly. Due to work with these tanks, the design of the dewar system is complete, and twenty-six additional pairs of vessels, which are being built outside the laboratory, will all be delivered this year. All of the other parts of the dewar systems are being built in-house as time and money permit.

With the exception of some difficulties with multi-layer insulation, the performance of the system is as expected. The heat leak into 1.85°K temperature will be about 1 watt total for each 20-foot length.

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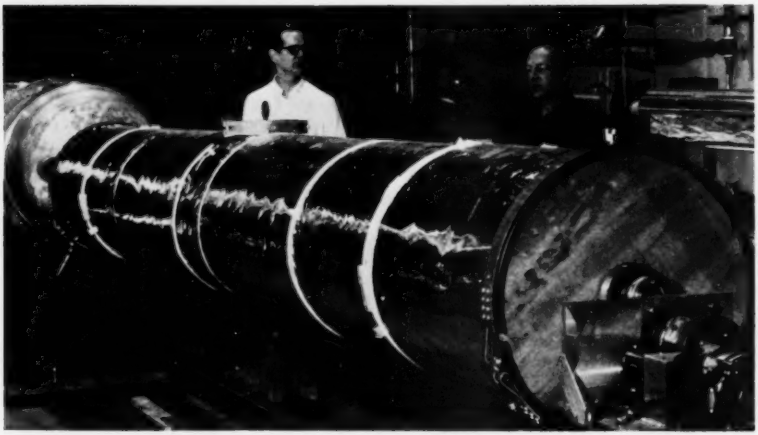

Figure 4 — Prototype 20-foot dewar module during assembly

(c) Distribution System: As is shown in Figure 2, the helium distribution system consists of three major parts: a 1-1/2 inch diameter line carrying liquid helium from the refrigerator, a 5 inch diameter line carrying cold helium gas back again, and two sizes of cryogenic valve units separating the dewar tanks from the piping.

The lines are straightforwardly designed, vacuum jacketed piping with liquid nitrogen shielding and multi-layer insulation. The piping is also built in 20-foot modular lengths to match the dewar system. The sizes were chosen so that the liquid helium can be circulated and the gas returned with pressure drops no greater than 1/2 torr for a refrigeration capacity of 1200 watts. This considerable overdesign was meant to provide for future expansion of the refrigerator and to allow easy extension of the system to other parts of the laboratory. Two such extensions are shown in Figure 2. There are lines to the end station to supply superconducting magnets and cryogenic targets, and the "superfluid faucet" which is a system to raise liquid helium to ground floor level by means of the fountain pressure. Other large-scale experimental apparatus in the laboratory would be connected into the system in a similar way by means of pipelines and valves.

The cryogenic valve units have a very important part in providing flexibility and convenience in the laboratory cryogenic system. They are in effect abscission points that separate and thermally isolate the cryogenic systems and permit one system to be warmed up and disconnected while the others remain in service. Thus any one of the seven accelerator dewar units may be repaired without affecting the rest, or

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the piping may be modified while the seven vessels store the liquid helium. This capability greatly simplifies the operation of what would otherwise be a very unwieldy system.

At this time the design of the piping is complete and much of the material has been delivered. The cryogenic valves are not quite as far along. Assembly of the distribution system commenced in January 1970, and will proceed as rapidly as the manpower permits. The intention is to complete this system in advance of the accelerator, so that as the accelerator grows, new units can be placed in service with very little interruption of operations.

The use of very low temperature on a large scale has in the past been considered an expensive and troublesome solution to an otherwise impossible problem. There is no reason for this. Superconducting accelerators offer a great deal of promise in a great many areas of physics not only because they have properties unattainable by conventional techniques, but because they can compete with conventional machines economically as well.

NRL Develops Hydrocarbon Analyzer

Naval Research Laboratory scientists, in Washington, D.C., have developed a total hydrocarbon analyzer for monitoring organic contaminants in closed atmospheres which is presently being installed on Navy submarines. The analyzer may also be used in any closed system, in water or on land, to determine the hydrocarbon content of the atmosphere.

Following the research phases of the hydrocarbon analyzer project, prototype units were built at NRL and were checked out in operating submarines by NRL chemists and the ship's force. Based on the successful results of the prototype work, units have been built for the Navy.

The first commercial analyzer, which was installed and checked out on a Navy submarine in May of this year, is proving out successfully and others will soon be installed on other submarines.

In speaking of the new development, the scientists said that submarines operate submerged in the sea for many weeks with no contact with the outside atmosphere. Consequently, the ship's atmosphere must be purified continuously by removal of contaminants and revitalized by addition of oxygen. The Total Hydrocarbon Analyzer (THA) will monitor the ship's atmosphere for hydrocarbons, refrigerant gases, and other organic contaminants that heretofore could not be monitored without sending samples back to the Laboratory after the ship had surfaced and docked.

The developers said that the instrument is based on the principles of gas chromatography, which is an extremely effective technique for separating contaminant molecules from each other for identification and quantification. To avoid supply problems, specially purified submarine air is used in the new instrument as a substitute gas for the almost universally used helium.

A back-flush technique on the analyzer is utilized for determining the total hydrocarbon content of the ship's air sample, after the individual volatile compounds have been identified.

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Complex Military Decision Making

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Simple *vs* Complex Decision Making

The vast majority of decisions that a person makes, day after day, tend to be comparatively simple. Information that is received from the environment is quickly and easily translated into a particular form of action. For instance, observing the approach of a quickly moving object tends to produce a quick movement out of the path of that object. In technical terms: a specific stimulus leads to a particular, single response; usually a response that has been well learned is often enough practiced and is carried out at the instant when it is needed.

Most decisions made in a military setting are probably no exception to this rule. Even respondent decision making to enemy attack may frequently follow that pattern. For instance, radar identification of a hostile aircraft should, all other things being equal, result in the most appropriate response. If this response is the firing of a particular missile, at the point in time when the enemy craft is located at a particular distance, then that missile should be optimally fired at that distance. If a stimulus (a bogie) can only have a limited number of previously specifiable characteristics, then a well trained specialist (or team of specialists) should have the capacity (*e.g.*, in AAWF) to respond accurately or optimally. Psychologists and other scientists have investigated many of the problems and processes associated with simple decision making. Much has been learned about optimizing simple decision making, for instance: how information should be displayed, how much information individuals and groups can handle, how identifications are best made, and how decision making can be most accurate.

However, not all decision making in the military can be described as simple. Stimuli do not necessarily occur singly, or occur as unrelated (even if simultaneous) events. Not all stimuli and not all stimulus configurations can be related to one accurate or optimal response. For instance an admiral in command of a fleet may find his ships exposed to simultaneous or successive attack from hostile submarines, surface vessels, aircraft and so forth. In addition, the attacks from the enemy may be coordinated in a strategy, rather than consist of single events. In addition, it may not merely be necessary to avoid losses due to enemy action, but also to carry out an attack on some objective. In other words, the commanding officer may be exposed to interacting stimuli

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from various sources, and may have to make interacting (interrelated strategic) decisions based on the information he receives. He may have to make decisions that permit him to use alternate (in themselves complex) strategies, or even combinations of strategies. Decision making of this kind is anything but simple. Unfortunately the scientific knowledge we have gained about simple decision making does not apply to complex decision making.

Complex decisions are made less often than simple decisions, yet they may be vital to the efficiency and the survival of any military unit. Unfortunately we have very little research based knowledge about complex decision making. Because of the many factors interacting in this form of decision making activity, it is necessarily more difficult to design appropriate research paradigms. Although some efforts in the direction of studying complex behaviors have been made, they have not dealt with a scientific analysis of the characteristics or processes involved in complex decision making. Consequently there are a number of questions which remain to be answered. How much information can a decision maker involved in complex decision making handle? Can he be assisted by a group of auxiliary decision makers? What is the most efficient way of transmitting information to him? What are the optimal uses he can make of digital or analog computers and display systems? When is he likely to take unwarranted risks, and when is he likely to be too cautious? How is he affected by partial failure or success of his mission? How can he optimally divide his attention between more important and less important information? Can he sort information that is relevant to his mission from information that is not relevant? Can or should he monitor the effects of his past strategy? Is he able to change from one strategy to another, if necessary? How many strategies can he maintain simultaneously, or combine into a single series of decisions?

This research program, which is sponsored by the Office of Naval Research, is attempting to find answers to these, and to other related questions. Research over the last two and one half years has begun to answer some of the questions. The purpose of this paper is a review of some of the results that have been obtained so far. Before looking at data, however, let us first take a look at the research setting that has produced these results.

The Research Technique: the TNG Experimental Simulation

The item "simulation" is familiar to most researchers and technical staff in engineering and the natural sciences. Simulation employs a representative model of a "real" object, with most of the relevant characteristics of that object. In addition, simulation permits the scientist to control the events that influence the "behavior" of his model throughout

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the simulation, so that the response characteristics of the model can be clearly identified and the corresponding response characteristic of the "real" object can be estimated. For instance, the flight characteristics of an aircraft can be estimated by the effects that changes of air movements in a wind tunnel have on a model of that aircraft. Simulation in the social sciences, where the responses of humans are involved, has usually had only one of two standard simulation components. Simulations of decision making behavior, as for instance carried out by Harold Guetzkow in his Internation Simulation (INS), has established very useful models of an internation setting at a particular point in time, within a set of specified recent and current events. Once such a simulation is begun, however, the social scientist has lost his influence over ongoing events in that simulation.* While the physicist or aircraft engineer can modify the events in his wind-tunnel, the social scientist has to let the participants in the simulation determine the events to which they respond. Although there are many values in this kind of simulation, there are necessarily some limitations. It is, for instance, impossible to determine what environmental events will produce specific changes in complex decision making: in other words, standard social science simulation techniques cannot answer the questions about complex decision making that we have posed above.

To be able to answer those questions, we must change social science simulation techniques. For that purpose we developed an "experimental simulation" technique, which contains fewer components than Guetzkow's INS, but permits continuous experimenter control over ongoing events. In our Tactical and Negotiations Game (TNG) participants make complex military decisions in response to experimenter controlled information. Although participants in the TNG believe that they are playing against another team of decision makers, all information that they receive is preprogrammed, with the characteristics of the program determined by the research intent of the experimenters. The specific design of the TNG, the characteristics of the program, and the "realism" of the setting in which the game is held, have consistently left participants with the belief that the events are effects of their own and the supposed "opposing team's" decisions. None of the participants have viewed the information they received as originating from a program. This design of the TNG, then, permits us to assemble individual decision makers or decision making groups and expose them to a military environment with specific characteristics: an environment that attempts to be representative of the model to be simulated. In addition, by controlling the information that these decision makers receive, we can modify the characteristics of the environment at will, so that the effect of specific events (*e.g.*,

*Training games, as often used in the military, are frequently also affected by the decisions of the participants.

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quantity of information, success, failure and so forth) on complex decision making can be accurately measured. Planned changes in the model (the general rather than programmed specific characteristics) can estimate to what extent our findings are effects of specific conditions, and to what extent they are more general. In other words, this manipulation may permit us to estimate potential generalizability of the results for real world (military) application.

Data and Implications: What Affects Complex Decision Making?

What are the effects of group size, environmental characteristics and demands on complex (simulated) military decision making? Let us turn to some of the results what we have obtained so far. We will first be concerned with the relationship between decision making quality* and the number of persons engaged in responding to environmental information. In a simple environment, where a particular event should lead to a particular response, more persons can make more simple decisions. If, for instance, it were possible to assign a missile to each bogie that is sighted, then each decision maker (or man-machine decision making team) can respond separately and efficiently.

In a complex environment, where each event has implications for each other event, all information (or at least much of the information) must be processed together (so that relationships become obvious) and decisions must be made with all events in mind. Does a team of decision makers respond better than an individual, or do the individuals of whom the teams consist "get into each other's way?" In our research we have used individuals, two-man, four-man and eight-man teams. We have found that individuals are as efficient as larger groups of decision makers: adding co-decision makers with joint responsibility does not improve the quality of complex decision making, even though it can increase the quantity of simple decision making. However, individuals as well as groups involved in complex decision making are greatly affected by the amount of information they receive. Decision making quality for groups and for individuals engaged in complex decision making tends to be low, when the quantity of information they receive is too limited or too great. In several replications of the experimental simulation we have determined a specific quantity of information but that produces the best

*It may be useful to define what we mean by decision making "quality" under complex decision making requirements. We are referring to (1) perceiving and understanding the interrelationships between information that is received, and (2) responding to as many items of information as possible in as few responses as possible (economically) while maintaining as many goal directed interrelated strategies as possible within environmental constraints. Experimental measurement of "decision making quality" takes all parts of this definition into account by assigning numerical values to each decision with reference to each of the components of that decision. Total decision making scores are then obtained by calculating orthogonal measures according to a number of formulas.

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complex decision making: one item* of information received by the decision maker (or the decision making group) every three minutes. Decision making quality is still relatively high when information is received in intervals of 2.5 to 3.75 minutes. However, information received as rarely as every 6 minutes or as frequently as every 2 minutes produces severe decrements in decision making quality.

If an individual operates as well as a group, then it might be useful to use other available personnel in a different function. They might for instance be useful as screeners of information, and assist the decision maker by "feeding" him information at the optimal rate of one item of information every three minutes. Whether this method of divided "group information processing" results in improved decision making quality when high quantities of information must be processed will be researched during the coming year.

What are the effects of partial success and failure in a decision maker's mission? For instance, how is the commander of a fleet affected by the loss of (or damage to) one of his ships per se (independent of the military value of the unit)? We have found that some amount of success or some amount of failure can be beneficial to complex decision making, but that this benefit can be realized only when the amount of information a decision maker receives remains below the "one item of information every three minutes" quantity. Large amounts of success information are slightly more beneficial than similar amounts of failure information. When all or nearly all information communicates failure, then the quality of complex decision making declines to near zero levels. Similar effects are obtained when all or nearly all information communicates success: apparently the highly successful decision maker ceases to care, or begins to feel that he cannot make a mistake in the face of what he tends to view as an "inferior" opponent. Generally, high levels of success, high levels of failure and high levels of information flow tend to produce a change in the decision making process itself. Decision makers cease to employ strategy and begin to respond to information in a one-to-one fashion. In other words, they cease to make complex decisions and begin to make simple decisions.

Many military decisions contain some levels of risk. In our setting, we have (somewhat arbitrarily) defined risk as the number of military units (troops, ships, aircraft, *etc.*, depending on the purpose of the analysis) invested in a non-defensive operation which could lead to the loss of these units. In this analysis, we find a similarity between simple and complex decision making. Risk taking by decision makers faced with

*An item of information presents information on only one judgmental dimension. For example: "Enemy activity has been observed at sector E/5" qualifies as a single item of information. If both location and enemy strength were reported, the information would represent two items of information. More precise measurement of information in information theory terminology (bits & bites) is not meaningful in complex decision making, since any information may both increase and decrease uncertainty.

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complex requirements increases with the time that a decision maker is involved in the task without interruption: highest levels of risk are reached after approximately six hours of decision making activity. Risk levels tend to stabilize somewhat at that point. However, the quantity of information to which decision makers are exposed also influences risk taking. Highest risk levels are obtained when decision making quality is highest: when information is received at the rate of one item every three minutes. Lower information quantities produce considerably smaller risk levels. High quantities of information flow, however, result in only a minor decrease in risk taking. This finding suggests a potential danger: under high information levels decision makers may engage in decision making that is simultaneously of low quality (see above) and of moderately high risk. It may be quite important to avoid information flow situations that would produce military decision making with these characteristics. Whether that can be achieved by use of a staff of information screeners, or by some other method, remains to be determined by future research.

While research by several investigators who were concerned with simple decision making has found that persons "in control" tend to take higher risks than persons who are not in control, we have found the opposite to be true for complex decision making. Persons in control (or command) tend to take lower risks. In other words, an officer who is faced with complex decision making requirements is not as likely to make risky decisions when he is placed in command, than he might have anticipated before he was placed in that situation. Similarly, a person following orders might "overinterpret" those orders, if he can assign the responsibility to a superior. And, finally, perceiving that the enemy is gaining more and more control over a military situation, might lead a decision maker to engage in greater and greater risks.

Both failure and success information also appear to affect risk taking. As either failure or success increases, risk taking increases greatly. High levels of either failure or success (70 percent or more success information, or 70 percent or more failure information) result in an abrupt change in risk taking characteristics: risks cease to be associated with complex decisions. They are now associated with simple decisions, are not part of any strategy, and reflect little or no long term intent. This form of risky decision making would make it easier for an enemy (who is not similarly affected) to gain control of a military situation. In other words, high levels of success and failure not only lead to poor quality of decision making (*i.e.*, simple decision making where complex decision making is required), but also to high risk levels associated with these poor decisions. It appears then, that environmental characteristics producing exceedingly high levels of information flow, high failure and high success information configurations should not be transmitted as such to personnel engaged in complex decision making.

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One other finding about risk taking may be of some interest. We have been concerned with comparisons between officers, students enrolled in ROTC programs, and general college populations. Although we have so far not obtained great differences between these groups on most measures of decision making quality, we have obtained considerable differences in measures of risk taking. Officers with several years of experience tend to take the smallest risks, followed with considerably greater risk levels by ROTC students and with yet greater risks by general college students (at four different Universities in the mid-west and the east coast).

One of the most frequently studied variables in decision making research has been the effect of information relevance. Relevant information has been generally defined as any information to which a meaningful (or correct) response by a decision maker is possible. Research from signal detection, perception and concept formation areas have shown that there is no single effect of information relevance on simple decision making. Increases in relevance may result in improvements or decrements in simple decision making. The data we have obtained about the effects of changes in information relevance on complex decision making are much more clear. It appears that decision makers involved in complex decision making can sort some irrelevant information from relevant information, but cannot distinguish clearly between all relevant and irrelevant items of information. Consequently, the quality of their performance is lowered by the inclusion of irrelevant information in the flow of information they receive. For optimal quality of their decision making, all information they receive should be relevant to the specific tasks at hand. For instance, transmitting information about unrelated or marginally related events to a commanding officer who is currently engaged to capacity in making decisions about a military confrontation, may have rather detrimental effects on the decisions he makes. This detrimental effect, however, may not occur, if the information flow to that officer was previously much below the value of one item of information every three minutes.

The TNG Model and Generalizability of Research Results

The research results obtained so far tend to fit a pattern that suggests that various environmental effects can combine to produce particular joint and interactive effects on complex military decision making. These results suggest that specific action can be taken to assist the decision maker in his task. Although that in itself is greatly encouraging, we are even more encouraged by the replicability of the results we have obtained, when the characteristics of the TNG simulation are drastically modified. This capacity to modify the general setting without affecting the data collected in each setting suggests that the results we have obtained

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have likely general applicability, and are not bound to a "real" situation which is in all its characteristics highly similar to the TNR model.

Current and Planned Research

Research in which we are currently involved, and research planned for the future, will be concerned with other effects of information characteristics, group structure and demand characteristics (*e.g.*, the explicitness of orders received) on complex decision making. Research in which we are currently engaged and research that will be initiated in the immediate future will specifically focus on two problems: (1) how can the decision maker in a complex setting be best assisted by others (*e.g.*, through information screening), and (2) how do differences in importance and/or urgency of selected information inputs affect complex decision making (*e.g.*, how can one assure that "emergency" information will not result in a simple decision, if simple decision making is inadequate for that particular situation.)

Because of the relatively "unexplored" nature of complex decision making, many problems with specific applications to military missions are yet to be investigated. The long range intent of the research program, however, is not only to gain greater knowledge of each component or process of complex decision making, but also to determine the interactive characteristics among them. In this fashion we should be able to obtain a more precisely delineated picture of the joint effects of all components and processes involved in complex military decision making. As a result, the research program should give us a greater understanding of how complex decision making can be optimized, both in terms of decision quality and in terms of manpower and cost economy.

New Complexities in Combustion

Dr. B. S. Rabinovitch under ONR contract has for some years been examining the results of the reactions of hydrogen atoms with hydrocarbon molecules containing a double bond. In general, the hydrogen adds to one of the double bonded carbon atoms with a release of energy and the formation of a radical, *i.e.*, an incomplete and therefore reactive molecular fragment. Such fragments are known to be intermediates in various kinds of combustion processes. In examining the redistribution of the energy imparted to the radical by the hydrogen atom addition, he has made an unprecedented finding of the transfer of an H-atom to the radical carbon atom from the nearest neighboring carbon atom. For a hydrocarbon molecule containing nine carbon atoms, eight different nine-carbon radicals can be formed, each of which would produce different end products when the excitation finally dies out. This new found behavior of combustion intermediates must be added to the other modes of redistribution of energy in excited radicals. The combustion process is thus seen to be far more complex than previously thought.

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Magnetic Semiconductors

M. A. Garstens
Office of Naval Research

Two well-known fields, that of magnetics and semiconductors have recently come together; the synthesis may have great technological importance. The synthesis involves the coupling of magnetic and electronic states in a variety of ways, which promise the production of a large number of devices based on new principles. Compact devices can be anticipated since the electron spin can couple magnetic and electric circuits internally without the need for inductive coupling. Variations in the conduction carrier concentration, produced locally by electric fields, light radiation, carrier injection and by other means, can give rise to variations in the local magnetic order. Thus, applications to laser technology can be foreseen in which the electronic state of semiconductors strongly influence their magnetic-optic properties. Modulations of a polarized laser beam could thus be accomplished at electronic frequencies which recently have been remarkably high in semiconductors. The effects of magnetic ordering in producing large variations of electrical and optical properties in some instances suggest applications in semiconductors which allow control of new variables by means of a magnetic field. The potential for applications and understanding solids in this field is great and may open many new avenues for basic and applied research.

Since magnetic semiconductors have good band conductivity as well as magnetic order, two different descriptions of the corresponding states are needed. The band structures of such materials are very complicated, containing band states as well as localized states. Transition element compounds (1), which give rise to semiconductors represent the largest but least understood group of solid state materials. They have the important property that strong interaction occurs between the d or f electrons (*i.e.*, electrons in the d and f shells) making them magnetic, but with the capacity of suppressing the electrical conduction process predicted by band theory for materials with energy bands which are partially filled.

In the literature of solid state physics magnetism presently takes on an entirely different direction in solving its many body problems from that taken by semiconductors. In the former (magnetism) one starts from the many-electron model of the single atom since the magnitude of the atomic magnetic moment and its g-factor can easily be calculated from the Hund rules and the Russell-Saunders coupling scheme. Perturbations due to the lattice environment can then be taken into account by assuming electrostatic crystal or covalent ligand fields, thus modifying

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the arrangement of the electron spins and the orbitals in the ground state. Basically a local picture for the distribution of magnetic spin is thus maintained. When long-range order becomes important, as in metals, difficulties in theory arise where one argues for localized or itinerant electron models. In nonconductors where long-range order may be important (*i.e.*, garnets or ferrites) satisfactory theories exist to take care of such effects (*i.e.*, superexchange and molecular field theories) except when conductivity effects are to be taken into account. Conductivity effects due to the movement of electrons between excess holes are partially explained by the so-called theory of "hopping" (2).

Where transport properties are dominant as in metals and semiconductors, the band theory has been most popular. It gives a very adequate description of such properties. Here interaction among neighbors is assumed to be much stronger than electron atom attraction. As a consequence, the electrons screen one another and are capable of moving freely through the lattice. But such materials do not favor the formation of magnetic moments. The many-body problem of combining conducting and magnetic properties in the material is one of great complication. There is, in addition, the interesting question as to whether a state intermediate between the conducting and magnetic states can exist. It is conceivable that two different thermodynamic states are involved. The transition from one to the other is under thorough examination and is known as the "Mott" transition. Little is known, however, of the mechanism of this transition. The change from one state to the other can be caused by pressure, heat, and other external means. These constitute a clue to some aspects of the transition mechanism.

Previous studies of magnetic compounds (usually oxides) have indicated that the "hopping mechanism" mentioned earlier is the usual cause of whatever conductivity exists in them. This makes them of dubious application value since the number of charge carriers available for transport is too small. Newly discovered materials, however, (*i.e.*, doped nickel oxide and rare earth chalcogenides) have been found to combine both hopping and narrow band conductivity with very adequate numbers of charge carriers for application to electrically controlled magnets and magnetically controlled semiconductors. Thus, at the border between the magnetic and the conducting state, there is strong interdependence among electrical, optical, and magnetic ordering properties.

A widely used theory of magnetic semiconductors has been developed by Ruderman Kittel-Kasuya and Yoshida known as RKKY. It describes the simplest version of a magnetic semiconductor which current theory can handle. In this model free carriers are available while atomic moments are strongly localized. The number of free carriers in this case can be controlled by excitation (thermal or optical) by injection and by other methods. In this model long-range interaction among atoms is attained by the partial polarization in the conduction electrons through the

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magnetic moment of the local electrons. The interaction between the conduction and magnet moment electrons producing this polarization is known as the (RKKY) interaction (also indirect exchange or exchange *via* itinerant carriers) and results in a Curie temperature which depends on the density of carriers, their momentum, a local exchange constant and the Fermi energy. The Curie temperature increases with increasing carrier density, exchange constant and magnetic moment but goes inversely with the Fermi energy. The (RKKY) interaction in solids is important in this discussion since the parameters which determine its strength also determine the degree to which conductivity effects magnetic order and vice versa and hence the technical applicability of the material. Most conductors and semiconductors are broad-banded with weak (RKKY) interaction and hence have only weakly polarized carriers. These are, therefore, not so interesting technically since magnetic variations (*i.e.*, changes in the Curie temperature) cannot be so easily produced by variations in conductivity. To illustrate the aforegoing we examine a series of materials, currently under investigation, which cover the range from strong to weak interaction between carriers and local magnetic moment. The materials we will refer to are the perovskites, spinels, chalcogenides and transition metal oxides.

The perovskites are minerals having the composition $CaTiO_3$. By replacing Ti by Fe, Mn or Co, we obtain a magnetic perovskite-type oxide of the formula $XFeO_3$, $XMnO_3$, or $XCoO_3$ where X is a large metal ion such as La^{3+}, Ca^{2+}, Ba^{2+} or Sr^{2+}. These oxides have cubic crystal structure (Figure 1).

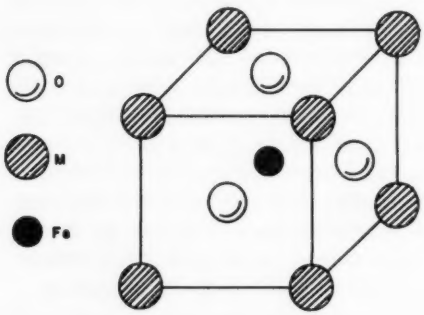

Figure 1 – Crystal structure of perovskite-type magnetic oxides

Early in the investigation of conductivity of magnetic materials the startling discovery was made that the perovskite $LaMnO_3$ could be made ferromagnetic by the introduction of a deficiency in oxygen or the partial replacement of La by Ca or Sr which gives rise to conductivity in the material. It was found that the ferromagnetism arose from the removal of a distortion in the perovskite cubic lattice by substitution of Ca or Sr

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giving rise to a superexchange reaction, a reaction between the spins of the metal ions *via* the oxygen ion separating them.

Some of the 3d compounds of sodium chloride structures show interesting interaction behavior. Thus, Li(0.1)Mn(0.9)Se(Li doped MnSe) is ferromagnetic between 70 degrees K and 110 degrees K and nonferromagnetic outside these limits. Superexchange, indirect exchange and double exchange have all been invoked to explain this phenomenon which is still not clearly understood.

The chalcogenides provide among the best examples of the dependence of magnetic order on variations in electrical properties. Thus, Eu-chalcogenides of NaCl structure with n type conductivity undergoes an increase in Curie temperature when the Eu^{2+} is replaced by tri-valent rare earth ions such as Ga^{3+}. The increase depends only on the change in conduction electron concentration but not on the concentration of impurity ions or the magnetic properties. Thus, if Ga^{3+} is kept constant while Eu is removed, reducing conductivity, a Curie temperature decrease occurs. In EuO one of the largest increases in Curie temperature occurs when Ga^{3+} is introduced. Several models to explain the phenomena have been introduced. A favored one suggests the formation of magnetic impurity states by electrons bound to the donors. Magnetic impurity states have the interesting feature of exchange interaction between localized ion spins and the bound electrons. As a consequence the sphere of influence of these states is a function of the degree of magnetic order in the lattice, thus affecting the Curie temperature.

The 3d-oxides are particularly important in magnetism-conduction transition problems since they are very sensitive in transition, to many external and internal parameters. One thus observes a great variety of 3d-oxide materials and transitions within them, from antiferromagnetic insulators to ferromagnetic metals and from gradual to abrupt transitions. Most changes in those materials are accompanied by both crystallographic and magnetic transformations. In most cases it is not clear as yet which of these two transformations is cause and which effect.

An interesting conductivity phenomena occurs in antiferromagnetic materials where the electrons are subject to double exchange. Here the conduction electrons can exist in several states, depending on their energy. If they move freely they tilt the aligned spins in the crystal. At lower energies this tilting is diminished but the electrons then travel in clouds of parallel spins moving slowly through the crystal and interacting strongly with the acoustic and spin waves in the lattice.

Since the Curie temperature is the point where large changes in magnetic polarization occur, corresponding changes in resistivity should also be manifested. In the magnetic semiconductors, changes in resistivity is commonly observed with changes in the Curie temperature. Some of these changes as in doped chalcogenides are orders of magnitude large. In EuSe a 10^7 resistivity increase and peak is observed. An external

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magnetic field causes a diminution in this peak. This is known as the giant magnetoresistance effect, a phenomena not too well understood as yet. Several mechanisms to explain it have been suggested. One makes use of an impurity model in which conductivity arises from the hopping of impurity electrons. Another assumes RKKY electrons which form in spin clusters at the point of maximum resistivity.

Some of the spinels such as $CdCr_2S_4$ show a different p type conductivity behavior at the Curie point than their n type behavior. Doping with gold or silver causes p type impurities while germanium causes n type impurities. While the n type spinels show an average resistance maximum at the Curie temperature the p type has a giant magnetoresistance effect at this temperature. Evidently the mechanism for resistance scattering is different for the two cases.

The usual band structure calculations are not sufficiently accurate for application to magnetic semiconductors. These calculations are based on the one electron approximation which does not apply when electrons are localized, as they are in magnetic semiconductors. A modification of the one electron picture is needed which will allow for partially localized magnetic electrons, having at the same time transport capacities. Approaches to this solution are as yet highly empirical and piece meal. A jig-saw solution is obtained by qualitatively superposing interpretations from all the various solid state disciplines; *i.e.*, observations of optical, chemical, magnetic and electrical properties. By this method, the conduction band picture (involving all electron wave functions) is combined, in an ad hoc way, with a localized magnetic picture (using localized many electron wave functions) to obtain further insight into these new interesting materials. There is a great variety of possibilities in materials here with great corresponding device potentialities. By varying the chemical binding, spin strength, size of ions (negative and positive) and their spacing, the lattice symmetry, irradiation, strength of interactions, type of doping, *etc.*, great flexibility in obtaining predesigned control of transport by magnetic strength and vice versa is possible. The overlap of the localized states with the band states in different ways produces great variation in material behavior. The magnetic semiconductors have all these potentials within them. One can envisage a development from current research which will make possible delicate control of any one of the parameters characterizing solids by any other; *i.e.*, optical, magnetic, electrical, mechanical, thermal and others.

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On the Naval Research Reserve

NRRC 4-1 Sponsors East Coast Oceanography Seminar

Eighty-seven reserve officers recently convened at Rider College in Lawrenceville, New Jersey for a two-week seminar on Oceanography. The seminar was sponsored by Naval Reserve Research Company 4-1 of Princeton, New Jersey. LCDR E. K. Snedeker, USNR, served as Seminar Chairman and CAPT E. C. Reichard, USNR, was Seminar Coordinator. CAPT D. M. Jewett, CO of the unit until relieved at the end of the fiscal year, served as Representative of the Commandant for the seminar.

The first day's program was begun by talks and a round table discussion by RADM O. D. Waters, Jr., USN, Oceanographer of the Navy; Dr. James H. Wakelin, Jr., formerly Assistant SECNAV for Research and Development and now Chairman of the White House Special Task Force on Oceanography (Dr. Wakelin is also a former member of NRRC 4-1); and Mr. Charles F. Baird, formerly Under SECNAV and now Vice-President of International Nickel Company. A keynote address was given at a banquet by CAPT Kent J. Carroll, USN, from the Office of Naval Research.

The major part of the program was devoted to discussion in greater detail of four specific areas of ocean science: marine biology, the space-sea interface, deep sea vehicles and considerations in submarine and ASW operations.

Cdr T. W. Bryant, New Research Reserve Coordinator Office of Naval Research Branch Office, Chicago

CDR T. W. Bryant, USNR, recently reported for duty as Research Reserve Coordinator, ONR Branch Office, Chicago, Illinois. CDR Bryant relieved CDR F. Whipple, USNR, who is assigned to Ninth Naval District Headquarters.

CDR Bryant entered the Navy in June 1947 and completed flight training in August 1953. He held various billets ashore and afloat in the aviation program. His last assignment prior to his present duty was at the Naval Reserve Manpower Center, Bainbridge, Maryland, as Head, Aviation Detailing Division.

LT H. C. Powell, Research Reserve Coordinator, Office of Naval Research, Pasadena, California

LT Harry C. Powell, USN, relieved CDR John P. Johnson, USNR as Research Reserve Coordinator for the Pasadena Branch Office. LT

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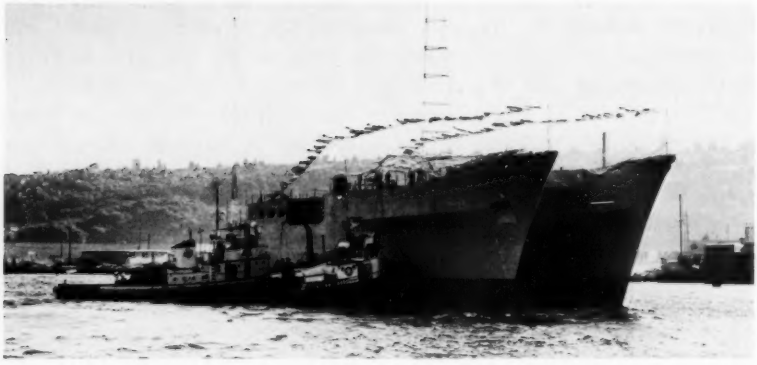
Powell graduated from UCLA in December 1966 with a B.A. degree in Psychology; he received his commission at that time through the NROTC regular program.

After schooling at Little Creek Engineer Officers Course, he reported aboard USS Rexburg (E)PCER-855 in February 1967 for duty as Engineer Officer. He served as Chief Engineer, USS Forster (DER-334) before coming to ONR, Pasadena in March of this year. LT Powell wears the National Defense and the Vietnam Service Medals.

New Oceanographic Research Ship



Tugboats move the USNS Hayes to a pier in the harbor at Seattle, Washington. The ship will be used by the Naval Research Laboratory in ocean acoustical investigations.

The Hayes, the first twin-hulled ship ever used by the Navy for oceanographic research, has an overall length of 246 feet and an extreme beam of 75 feet. She displaces 3,080 tons and provides ample space to accommodate 44 officers and men and 25 NRL scientists. Her wide and protected center-line well provides better facilities for the handling of equipment and will enable her to serve as a mother ship for small, deep submersibles, when needed.

Simplicity was emphasized throughout Hayes' design process. Most of her machinery and her scientific equipment will be standard, commercially-available instrumentation. Her design is calculated to permit better handling of oceanographic apparatus and to allow greatly increased space for laboratories. Scientific gear will be towed and recovered through a center well between the two hulls, as well as by the more conventional over-the-side handling techniques. Each hull is fitted with a controllable, reversible-pitch propeller. The wide separation of the two propellers, resulting from the double-hull arrangement, is expected to give Hayes excellent maneuverability and eliminate the need for the bow-thruster propellers used in earlier AGOR designs.

The ship was named in honor of the late Dr. Hayes for his scientific efforts in developing the Navy's fleet sonar system while employed at the Naval Research Laboratory from 1923 to 1947.

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Research Notes

Biological Fouling of Ship Surfaces

ONR is investigating the mechanism of fouling of glass surfaces by sea water at the School of Public Health, University of California, Berkeley, California, further support has been found for the concept that the process involves a community of biological forms. The primary stage appears as bacteria; as the numbers and types of bacteria increase (depending on nutrients, temperature, *etc.*) other organisms such as protozoa, diatoms and algae colonize the growing habitat. The orientation of the exposed surface in relation to the sea surface and prevailing currents can determine the participation of certain members of the community. There is clear evidence that the diatom *Melosira* prefers rough or sharp ledges for attachment. Chains of diatoms may extend over the surface and although many are easily removed by water flow, a few remain firmly attached to the glass. In addition stalked forms of organisms play an important part in providing additional surface area for entrapment of detritus and/or other organisms.

Big Casino

Those of us who are card players and who have played the game "Casino," will not fail to understand the significance of the title when it is applied to Nuclear Physics. For others, a short explanation might be in order. In recent years nuclear physicists have, with astonishing regularity, uncovered new elements in the Transuranium series. These elements have, in general, proven to be naturally radioactive with extremely short half lives. The last element to be produced was Hahnium, atomic number 105, announced at the most recent American Physical Society Meeting in Washington, D.C. in April 1970.

Because of the difficulty and little practical worth garnered from the slow advance of the scientific frontier in this field, scientists have dreamed of a more dramatic and, in the long run, a more economical method of moving forward. Nuclear shell model theory has confirmed the magic numbers of 8, 20, 28, 50, 82, for either atomic number or total nucleon number, as being particularly stable nuclei. The next "magic" number predicted by this theory is 126. Other theories predict "isles of stability" in the vicinity of 114. Clearly, attempts to reach these plateaus by present means would be slow, tedious and expensive. The conventional method for producing progressively heavy nuclei has been to accelerate low charge particles into heavy target atoms. This method has succeeded in raising itself by its bootstraps, increasing atomic number by one or two with each successful experiment.

It has been asked: "What would happen if a heavy ion could be accelerated into a heavy target?" Until the recent Gordon Research Conference this was largely an academic question. Production of highly ionized heavy atoms has not been possible, and a prerequisite for reasonable acceleration is a substantial charge to mass ratio. Several schemes have been under consideration lately for production of this highly ionized state. It has been calculated that at least 40, preferably 60, electrons need to be stripped from the uranium atom, creating states U^{40+} to U^{60+}, before the uranium ion can be realistically accelerated with enough energy to make the collision of two uranium nuclei scientifically interesting.

A scheme named HIPAC (Heavy Ion Particle Accelerator) has been developed recently by AVCO Everett Research Laboratories to accomplish the desired objective. Briefly, atomic uranium would be introduced into a high energy electron gas rotating in a magnetically confined torus. Multiple collisions of the high energy electrons with the atomic electrons would produce the highly charged ionic state. The ions would then be extracted

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through a minute hole in the torus by a magnetic bias and accelerated by more or less conventional acceleration methods, into a target of heavy nucleons.

What will be the result if we attain a stable super heavy nucleon? What will be the chemical form of the substance and its properties? Will it be conventional? If unconventional, will it revolutionize anything or perhaps everything? What will be its military significance? No one can answer questions, but unexpected dividends have resulted from similar deep excursions into nature's "catacombs."

The Navy Wars on Pollution

The Navy has been engaged for a long time in a war on environmental pollution, but the effects have not always been visible to the public. The program basically focuses on three areas: (1) ship pollution abatement, (2) aircraft pollution abatement, and (3) shore pollution abatement.

Corrective pollution abatement programs have been initiated in all areas, although some are still in the research and development stage. One significant program is the conversion of all oil burning ships to the use of distillate fuel, rather than "black oil." This change had long been advocated by the Naval Research Laboratory, since it will increase the efficiency and cleanliness of the ship as well as decrease air pollution.

Eliminating harbor and river sewage pollution by Navy ships is the most vexing pollution problem encountered by the Navy. However, the Navy has developed a prototype shipboard sewage treatment system (the first of its kind in the U.S.) which meets current Public Health Service guidelines, and with additional refinements and changes which will be necessary for larger ships, the research and development effort should soon obtain the required results.

Another program relates to jet aircraft operations which produce pollutants in the forms of smoke, noise and chemical products from the exhausts. Elimination of smoke is the most advanced action, and engine combustion chambers are being altered to decrease the other noxious products. Another aspect of aircraft operation which has other wide effects is the training of fire-fighters to extinguish fires resulting from aircraft crashes or other accidents on carriers. The large, smokey fires necessary in this training are slowly being contained by installation of smoke reduction equipment at major training facilities.

Air pollution problems at Naval facilities in the Los Angeles area have been minimized by a Smoke Emission Testing (SET) team from the Naval Civil Engineering Laboratory which monitors stack emissions for particulates and vapors in accordance with NAPCA standards and recommends corrective measures. The same Laboratory is also conducting research on oil pollution and sewage problems affecting shore facilities. The Naval Ship Research and Development Laboratory at Annapolis is also developing oil pollution and sewage control methods for ship operations.

However, few federal facilities can match the early date of 1928 in which the Naval Research Laboratory in Washington became actively engaged in atmospheric control. The emphasis at that time was on purifying the air breathed by submariners, and the need for the research was justified by a special Submarine Board which had investigated two submarine disasters. NRL has continuously been involved in atmospheric control ever since, particularly for submarines and other closed systems. The present nuclear submarines utilize the following air purification equipment (excluding the air conditioning units): a carbon dioxide scrubber which employs a regenerative amine absorber determined by NRL in 1953 to be the most efficient chemical available; a carbon monoxide burner developed by NRL, which also removes hydrogen and numerous hydrocarbons; an electrolytic oxygen generator; chlorate oxygen candles, developed by NRL as an emergency oxygen source; electrostatic precipitators, which NRL determined in 1958 to be necessary to remove

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aerosols from tobacco smoke and other sources; a composite atmosphere analyzer, initially developed by NRL to monitor the principal gases in the submarine atmosphere (carbon dioxide, carbon monoxide, oxygen, hydrogen, and refrigerant gases), and a hydrocarbon analyzer recently developed by NRL to monitor the total hydrocarbon content of the atmosphere as well as a few specific hydrocarbons of special interest—lithium hydroxide canisters for the emergency absorption of carbon dioxide.

A few examples of the relationship of this nuclear submarine equipment to the overall air pollution problem are quite pertinent. The present high capacity electrostatic precipitators used for removal of fly ash from heating plants or incinerators are the result of NRL research in the early 1950's on possible methods for collective protection from chemical warfare agents. The electronic air cleaner often used in home air conditioning systems is a modified version of the electrostatic precipitator. A catalytic burner similar to the ship's carbon monoxide burner, though possibly with a different catalyst, is to be used to curtail carbon monoxide and hydrocarbons in fuel exhaust from autos. The NRL total hydrocarbon analyzer is presently produced by three different manufactuerers, and there is a good possibility that one of these companies may decide to produce the analyzer commercially.

Another NRL study has discovered a surfactant which markedly retards the spread of oil on water, and the piston film generated by an extremely small quantity of the surfactant can actually push back the oil if the latter is no more than a fourth of an inch in thickness. The system has been applied on the Buffalo River and in Baltimore and Norfolk harbors with signal success, but energy considerations apparently limit its applicability in heavy seas.

Another research study at NRL covers the effect of pesticides on phytoplankton of the sea. Another biological problem has involved the reactions of sulfate-reducing bacteria on ship fuel, with the chromates previously used for counteracting the bacteria having to be replaced because of apparent harm to sea life when the chromates are discharged overboard.

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